Modal expansion functions combined with EFIE applied to Air Intake / Engine RCS computations.

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Abstract

In this paper we will describe a sub-domain method based on integral equations devoted to the RCS analysis of Air Intake and rotating fans. The accuracy and efficiency of theses techniques will be demonstrated for the CHANNEL ¼ scaled mock-up. During the computation a set of sub-domain will be calculated and connected in a final step. The RCS results will be compared with measurements on the CHANNEL mock-up for 2 frequencies. We will also discuss the accuracy of this formulation using a modal field expansion on a fictitious surface between the fixed and rotating wheels of the CHANNEL compressor.

1 Introduction

The electromagnetic scattering from the interior of a complex jet engine inlet contributes significantly to the overall radar cross section (RCS) of a modern jet aircraft. The scattering mechanism in jet or missile inlets are complicated and difficult to simulate accurately. The geometry is both complicated (engine face, structural obstacles, materials) and electrically large. Several authors have developed numerical methods in the frequency domain to solve this problem [2], [4].

ONERA has developed several years ago a modular multi-domain scheme based on generalized scattering matrix computations of 3-D sub-domains [5]. The global geometry is split into several sub-domains separated by a set of fictitious surfaces. Several expansion functions such as "Rao-Wilton-Glisson" divergence conforming basis functions [1], "modal" numerical basis functions [3] and "Deltagaps" basis functions can be used on these fictitious surfaces. For each sub domain (even the exterior 3-D volume), the generalized scattering matrix S is computed with different methods such as the 3-D FEM or the electric field integral equation (EFIE). Then, the different objects are connected together by solving a network equation. In the context of parametric investigations, the scattering matrices of the modified domains have to be re-evaluated, the other ones are simply re-used in the connection step. This "factorisation" scheme has been intensively used at ONERA, for Radar Cross Section applications. It has been demonstrated that this strategy reduces significantly the computation time compared to traditional hybrid methods for which a geometric or electromagnetic modification requires a new computation of the complete target. Furthermore, the condensed operators are totally independent allowing code and data protection during a multi-industrial aircraft project.

The sub-domain scheme applied to RCS collaborative computations of inlets consists in attributing a set of 3D volumes at each aircraft partner. In this way the air intake and engine structure may be graphically represented by a graph made up of (N+1) volumes and N interfaces. The scattering S matrix of each volume is computed with the EFIE. The RCS modulations induced by a rotating fan is easily processed by tuning the scattering matrix corresponding to the initial position. For each rotation angle, the engine sub-domain is computed and the graph equation is solved providing the new RCS patterns [6]. Furthermore, if a slight modification of the primary geometry is required, the new RCS pattern can be fastly computed. This point makes the method very suitable for air inlet applications.

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2 Sub domain formulation

The computation of an air-intake including a rotating fan is split in several sub-problems which will be connected at the end of the project. The main advantages of the method are the reduction of the computation time, the great modularity for collaborative calculations and an efficient RCS computation of the modulations induced by the fan rotations.

The target Ω is split into N sub domains (V_i) and M fictitious surfaces (Γ_j). Note that V_0 is an unbounded volume, and the volumes $V_1,\ldots,V_N$ are bounded. In each bounded or unbounded volume V_i of the decomposition, the boundary ∂V_i is made of n_i fictitious surfaces Γ_j and a part of Γ_0. The surrounding medium has permittivity ε_0 and permeability μ_0. The scatterer is illuminated by an incident wave $\vec{E}_{source}$, $\vec{H}_{source}$ with wave number $k = \omega/c$.

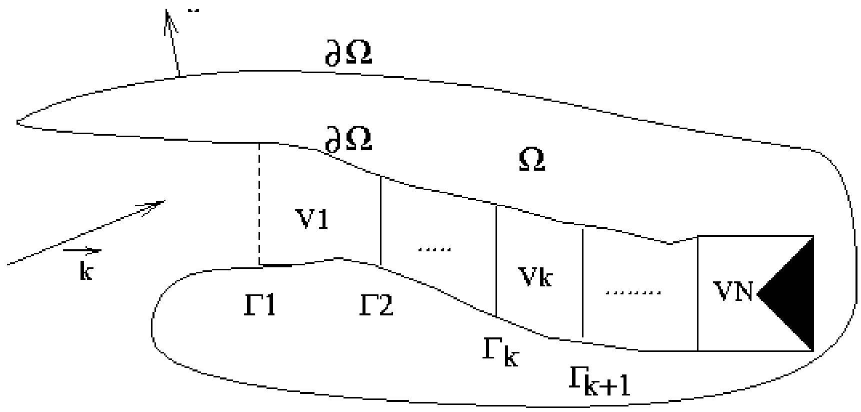


Figure 1 : target decomposition

The tangential fields are expanded with normalized wave-guided modes basis functions [3] on the fictitious surfaces and RWG divergence-conforming basis functions [1] on the other surfaces.

$$\vec{J} = \vec{n} \times \vec{H} = \sum_i J_i \vec{f}_i , \qquad \vec{M} = \vec{E} \times \vec{n} = \sum_i M_i \vec{g}_i$$

We shall now introduce these currents decompozitions in the EFIE formulations. By linearity of the Maxwell equations, the currents on each of the n_i fictitious surfaces Γ_j of the volume V_i is a linear combination of currents $\vec{J}_{source}$ and $\vec{J}_{excitation}$. The scatterer is illuminated by an incident wave $\vec{E}_{source}$, $\vec{H}_{source}$ located in the exterior unbounded domain V_0. EFIE operators P,Q,B,S ([5]) can be used in this formulation to compute $\vec{J}_{source}$ and $\vec{J}_{excitation}$ for both bounded and unbounded volumes:
$(B-S)\vec{J}_p^{\,j} = (P+Q)(\vec{K}_p^{\,j})$ and $(B-S)\vec{J}_{source} = 2P(\vec{E}_{source} \times n)$
The scattering matrix S of each sub-domain may now be calculated with the currents expansion on the sub-domain interfaces and with the currents $\vec{J}_{source}$ and $\vec{J}_{excitation}$. The sub-domains are then characterized by the relation $b = Sa + b_{source}$ ([5]) where the coefficients a are corresponding to the incoming waves in volume V_i and b the outgoing waves. Finally all the sub-domains are connected by solving the graph equation $(I-S)x = b_{source}$. Vector x is constituded with the incoming and outgoing waves on each fictitious surface of the structure. Then, once the vector x has been determined, the total electromagnetic field is recombined on the boundary of the exterior domain for all the incident waves.

In real life collaborative RCS computations of air-intake and engine structures, both aircraft manufacturer and engine manufacturer need to exchange datas characterizing their own sub-domain. In the previous numerical technique each manufacturer calculate the S scattering matrix of his sub-domain. If the current basis functions on a shared fictitious surface are different, it is necessary to perform a S matrix transformation before assembling the sub-domains. Then we have introduced a “mode to mode” and a “edge to mode” transformation.

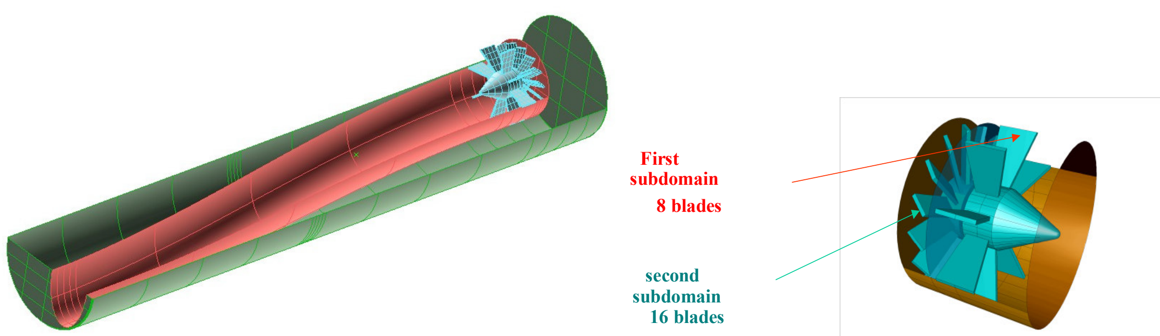
The blade rotations in the engine sub-domain is a particular case of S “mode to mode” matrix transformation. The challenge is to obtain the RCS for all the angular positions of the engine from the computation of a reference position. The scattering matrix S of the reference position express the incoming waves in function of the outgoing waves on each interface of the sub-domain relatively to a base f_p. The algorithm consists in writting the scattering matrix in a new base g_p. If P is the matrix transforming base f_p in base g_p, the scattering matrix expressed in the g_p base is derived by: $\widetilde{S} = P.S.P^t$. The modelling of the engine rotation is then realized with a simple rotation of the modal functions f_p.

3 Validations on the CHANNEL mockup

CHANNEL is a ¼ scaled mock-up. This mock-up is a slowly evolutive air-intake enclosed in a circular cylinder and terminated by a two blocks engine. The engine is consisted with a 8 blades fixed wheel followed by a 16 blades rotating fan.

Two frequencies are investigated: 7 Ghz and 16 Ghz. The total length of the mock-up and fan diameter are respectively 34.5 λ and 4.3 λ at 7 Ghz, 79 λ and 10 λ at 16 Ghz. The measurements are provided by ONERA. Computations and measurements patterns are provided for a scan angle θ from 80° to 135° for both ΦΦ and θθ polarisation.

In the computations a fictitious surface is introduced between the 8 blades fixed wheels and the 16 blades rotating fan. This point make the method efficient to use respectively an order 8 and 16 cyclic symmetry for the first and second engine sub-domain.



The first validation is obtained at 7 Ghz. We have introduced a spherical incident wave emitted at 8.73 m from the point (0.601;0;0) so as to reproduce the measurement conditions. The target is split in 5 volumes separated by 4 fictitious surfaces. The 5 Scattering matrix sub-domains are computed with the EFIE. The tangent fields on the air-intake fictitious surface are expanded with 120 modal functions. On the interface between the engine wheels 400 modal functions have been used. The 8 blades and 16 blades sub-domains are meshed respectively with 29856 and 37368 unknowns. We observe on Figure 2 that the results are in good agreement with the measurements.

The second validation is obtained at 16 Ghz. We have introduced a spherical incident wave emitted at 8.475 m from the rotation point so as to reproduce the measurements conditions. The target is split in 18 volumes separated by 17 fictitious surfaces. The 18 Scattering matrix sub-domains have been computed with the EFIE. The tangent fields on the air-intake fictitious surface are expanded with 540 modal functions. On the interface between the engine wheels 550 modal functions have been used. The 8 blades and 16 blades sub-domains are meshed respectively with 451752 and 115376 unknowns. We observe on Figure 4 that the results are in good agreement with the measurements.

Another important point is the efficiency of the sub-domain method to analyse the RCS modulations induced by the fan rotations. The inter blades distance of the fan is 360/16=22,5°, the RCS has been measured in the CAMERA2 chamber of ONERA for 4 positions (0°,5,625,11,250°,16,875°) spaced from 22,5/4=5,625°. By combining the advantages of the volume splitting allowing scattering matrix reusing of non modified sub-domains and the S matrix transformation for performing the fan rotations, the RCS modulations patterns are obtained very easily. The computation time needed to get the modulations patterns are less than 0.1 % of the cost of the primary calculation of the initial fan position. We observe on Figures 5 and 6 a good agreement between computed and measured modulations patterns. The level of modulation is approximatly 5 dB.m2 for both the measured and computed results.

4 Results at 7 Ghz

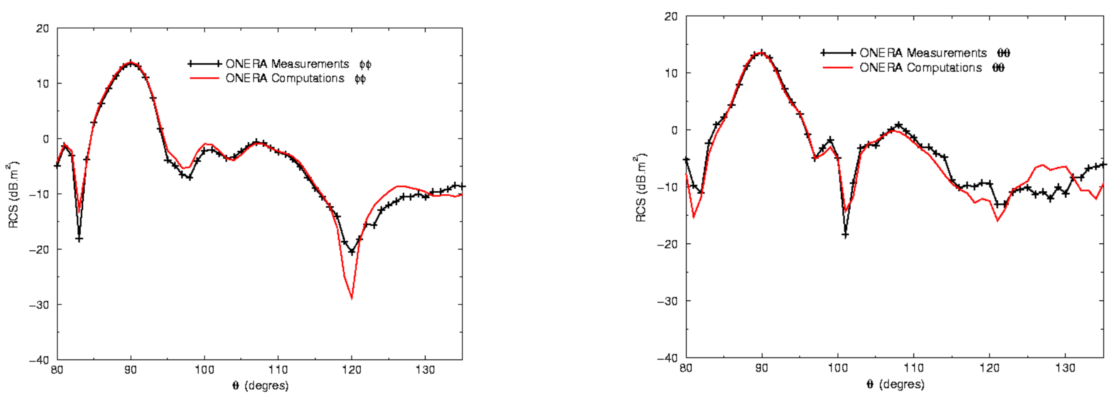


Figure 2 : Comparison of measured and computed near-field RCS , polar ΦΦ and θθ, F= 7Ghz.

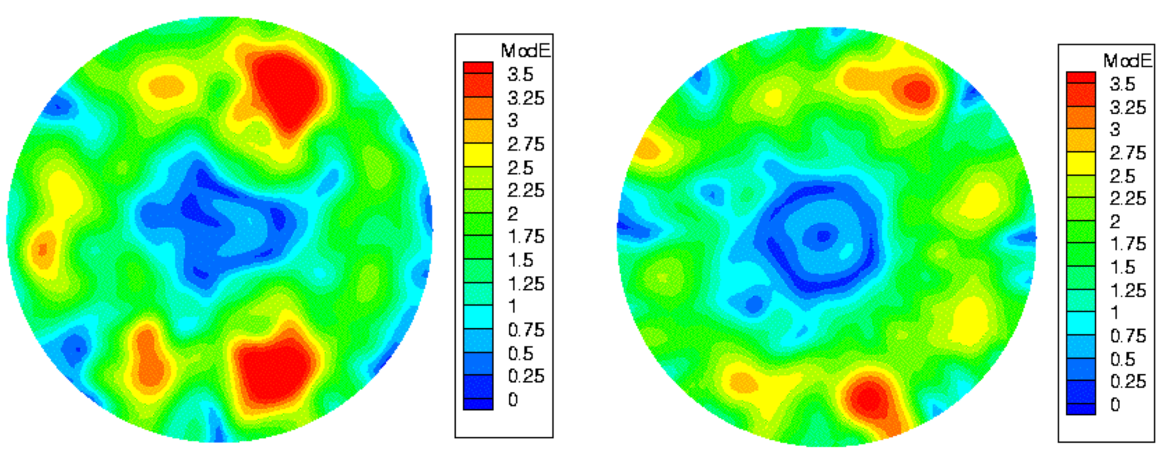


Figure 3 : Tangent electric fields on the fixed/rotating interface ; polar ΦΦ and θθ, θ=80°,F=7Ghz

5 Results at 16 Ghz

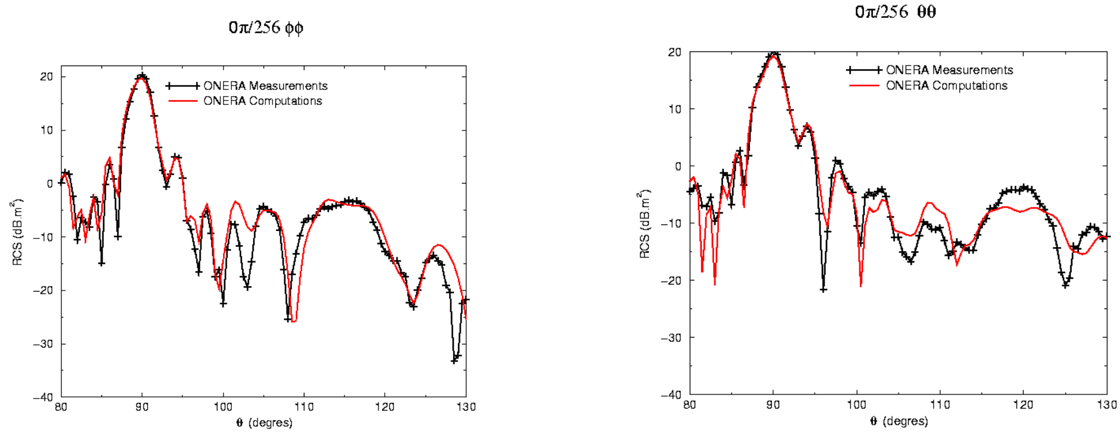


Figure 4 : Comparison of measured and computed near-field RCS , F= 16 Ghz.

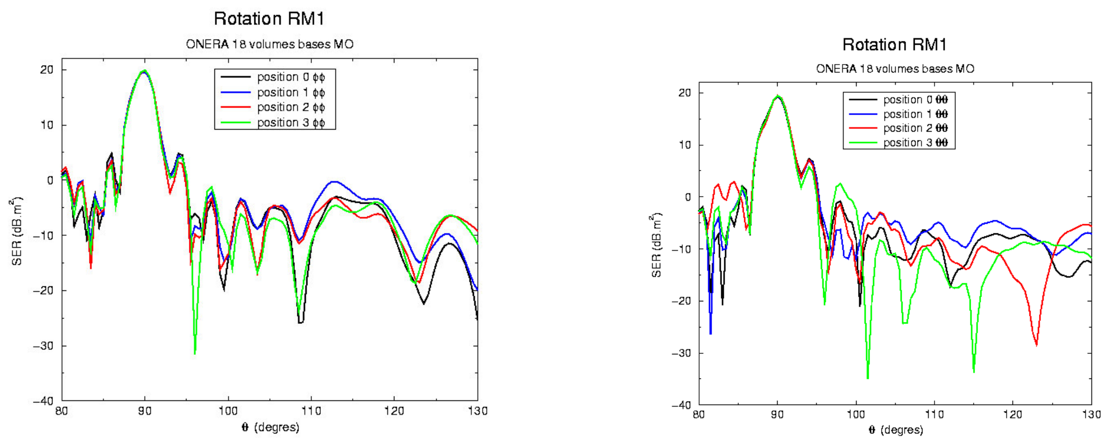


Figure 5 : Computed RCS modulations at 16 Ghz, $\alpha = 0°$, $\alpha = 5{,}625°$, $\alpha = 11{,}250°$, $\alpha = 16{,}875°$

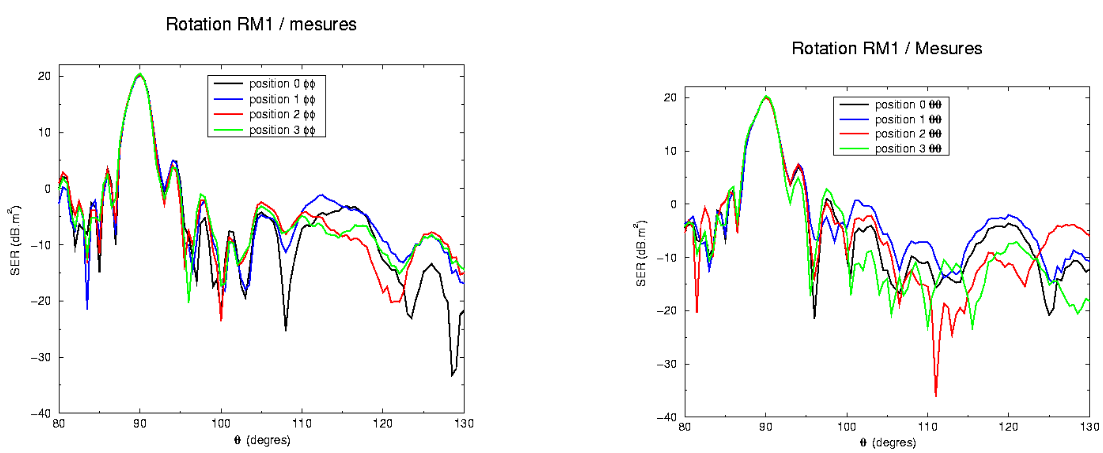
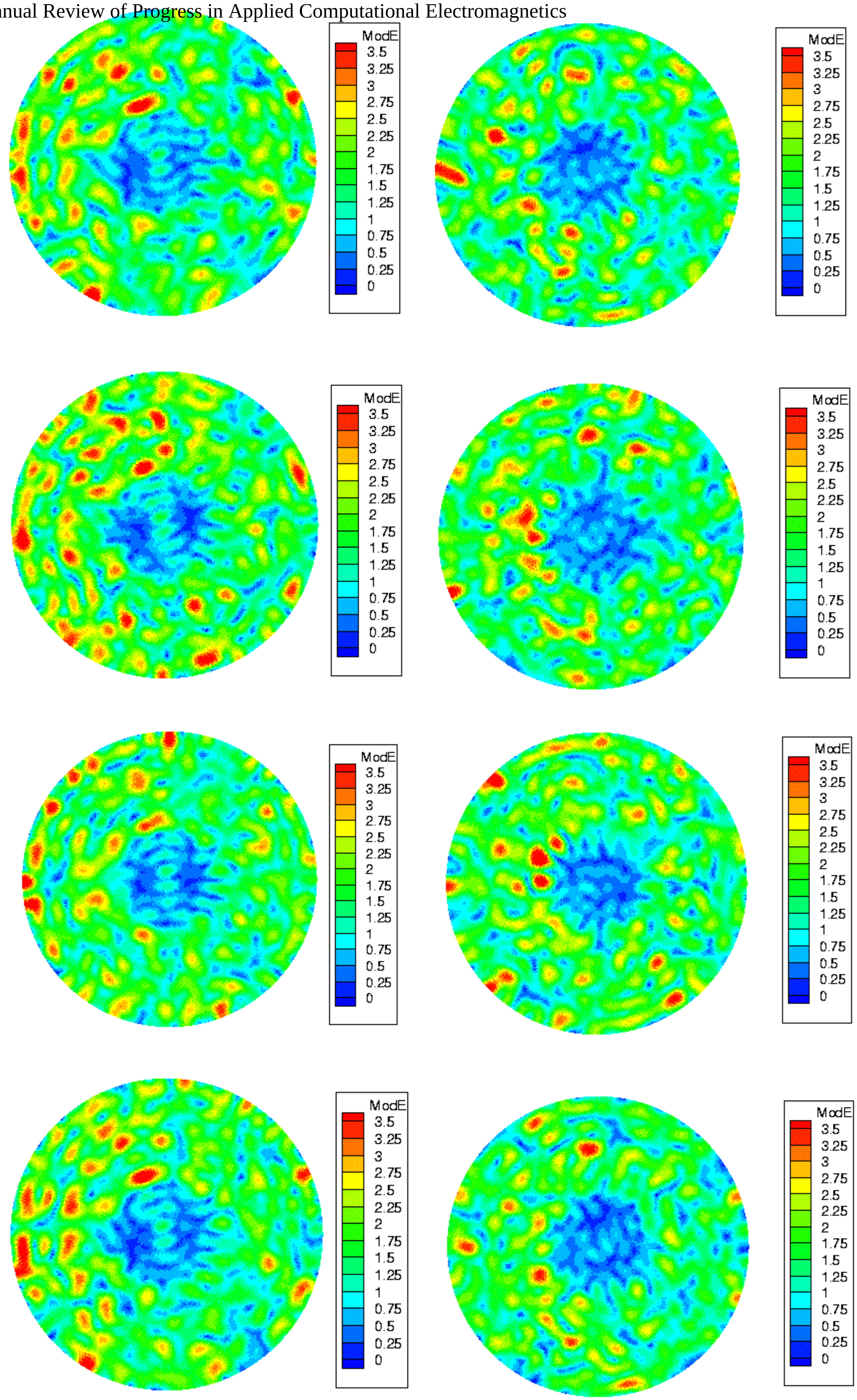


Figure 6 : Measured RCS modulations at 16 Ghz, $\alpha = 0°$, $\alpha = 5{,}625°$, $\alpha = 11{,}250°$, $\alpha = 16{,}875°$



position 1

position 2

position 3

position 4

Figure 7 : Tangent electric fields on the fixed/rotating interface ; ΦΦ and θθ, θ=80°,F=16 Ghz

6 Conclusion

In this paper, we have introduced a sub-domains technique for analysing the EM scattering from 3D cavities. The Electric Field Integral Equation is used to compute the generalized Scattering matrices of the sub-domains. Wave-guided modes are used for modelling the field propagation from the cavity opening down to the engine face. RCS patterns of the CHANNEL mock-up including modulations were presented and compared to measurements to show the accuracy of this method, the reduction in computation time and the advantages of this method for parametric studies.

7 Bibliography

[1] S.M Rao, D.R Wilton, and A. W. Glisson,
« Electromagnetic scattering by surfaces of any shape»
IEEE Transactions on Antennas and Propagation, Vol AP-30, May 1982.

[2] D.C Ross, J.L Volakis, H. Hannastassiu,
« Hybrid Finite Element-Modal Analysis of Jet Engine Inlet Scattering»
IEEE Transactions on Antennas and Propagation, **43**, n°3, March 1995.

[3] A. Barka, A. Cosnuau, F.X Roux,,
« Parallel organization of air intake electtomagnetic mode computation on a distributed memory machine»
La recherche Aérospatiale, 1995 , **n°6**.

[4] T.T Chia, J. Burkholder, R. Lee,
« The application of FDTD in hybrid methods for cavity scattering analysis»
IEEE Transactions on Antennas and Propagation, **43**, pp. 277-285, Oct. 1995.

[5] A. Barka, P. Soudais, D. Volpert,
« Scattering from 3-D cavities with a plug and play numerical scheme combining IE,PDE, and modal techniques»
IEEE Transactions on Antennas and Propagation, **48**, pp. 704-712, mai 2000.

[6] A. Barka, P. Soudais,
« A hybrid method combining EFIE and modal expansion applied to RCS modulation of antennas and rotating fans» Proc. of ACES Symposium, mars 2000.

[7] P. Soudais, P. Leca, J. Simon, Th. Volpert,
« Computation of the scattering from inhomogeneous objects with a discrete rotational symmetry and a non-symmetric part»
IEEE Transactions on Antennas and Propagation, **50**, février 2002.

